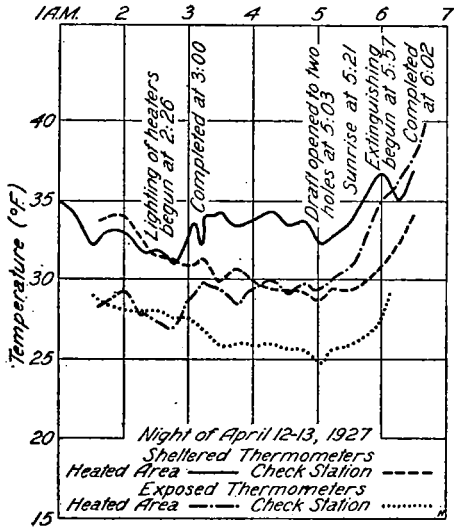
THE PROTECTION OF STRAWBERRIES FROM FROST THROUGH ARTIFICIAL HEATING

By ALBERT W. COOK

The strawberry is one of the best-paying soft fruit crops grown in the southern Yakima Valley of Washington. However, the financial success of the strawberry industry is dependent upon several factors, and among these, damaging late spring frosts play an important part. The annual loss to the strawberry crop is not constant, but varies from year to year. Some years there may be no frost, while in others a severe frost may kill the early bloom and seriously curtail the output of fruit. The continuance of the strawberry as one of the major soft fruit crops is dependent upon the solution of the problem of late spring frosts. Tests were undertaken by the Weather Bureau fruit-frost service to ascertain the possibility and practicability of protecting strawberry buds and blossoms from damage by frost by methods of artificial heating.



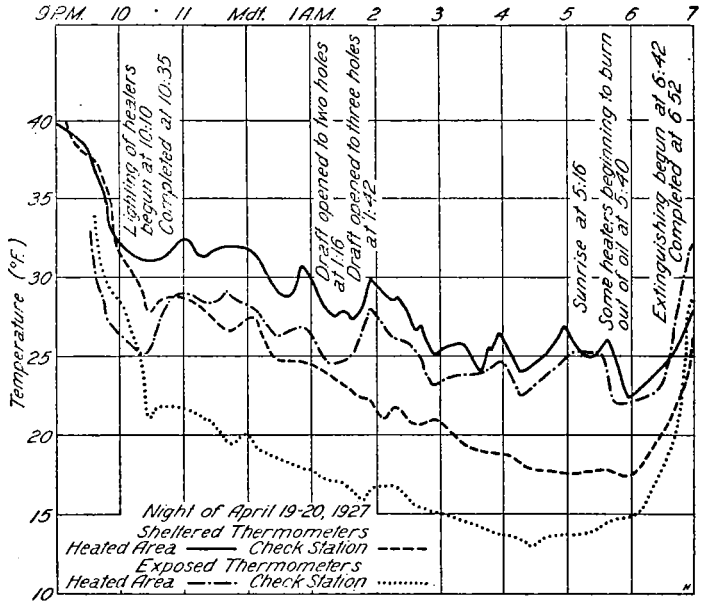
NOTES FOR FIG. 1—NIGHT OF APRIL 12–13, 1927

P. m.
5:00 Dew point, 29° F. Relative humidity, 29 per cent. Temperature, 61.5° F. Wind north 2. m. p. h. Sky clear 1 Ci-?
A. m.
1:48 Dew point, 26° F. Relative humidity, 65 per cent.
2:20 Frost forming on shelter top in patch.
2:26 Lighting of heaters begun.
3:00 Lighting completed.
3:02 Frost melting on shelter in heated area. Beginning to melt on plants.
3:12 Drafts cut down to slightly less than one hole. Frost melting on plants 9 feet from shelter.
3:18 Frost heavy on shelter at check station. Alfalfa adjoining strawberry patch heavy with frost. Very light southerly drift.
3:30 Some frost on shelter in heated area. Dew on exposed thermometer in heated area. Some light frost on plants in heated area about 7 feet from heaters.
3:34 No appreciable drift. Flames rising vertically.
3:50 Westerly drift—about 4 miles per hour.
4:10 Ground dry 8½ feet from heaters. No frost 10 feet from heaters.
4:15 Frost on top of shelter in heated area. Westerly drift—4 m. p. h.
4:50 Smoke rising vertically.
4:56 Light frost showing about 8 feet from heaters.
5:03 Draft opened to two holes.
5:21 Sunrise.
5:22 Frost showing on part of leaves about 7½ feet from heaters.
5:57 Extinguishing of heaters begun.
6:04 Extinguishing of heaters completed.

No frost on alfalfa 6 feet south of south row of heaters and 7 feet north of north row of heaters.

Blossoms marked before heating was necessary in all parts of the patch showed no injury upon examination following day.

It was deemed advisable to conduct the investigation, as far as practicable, in a typical patch fully representing the various circumstances existing and under natural frost conditions. The tract selected for the test was located about one-fourth mile south of Kennewick. It was a little less than 1 acre in size, sloped gently toward the northeast, and was planted to Clark Seedling strawberries 4 years old. It was equipped with double-stack 3-gallon, oil-burning heaters placed 20 feet apart on the square. (See fig. 4.) The outside row of heaters was placed 5 feet inside of the outside edge of the patch, and no border row was used. The heaters were mounted upon tripods (fashioned of heavy wire twisted to form the legs, thus making at the top a rest upon which to set the heater) so that the top of the heater stack was 30 inches above the surface of the plants. Ninety-six heaters were used, burning 24° gravity crude oil.



NOTES FOR FIG. 2—NIGHT OF APRIL 19–20, 1927

P. m.
5:00 Dew point, 15° F. Relative humidity, 24 per cent. Temperature, 49.2° F. Wind northwest 14 m. p. h. Sky partly cloudy 5 StCu-West.
9:00 Wind from northwest but decreasing in velocity.
9:30 Wind decreasing; temperature beginning to fall.
9:45 Very little wind; decided fall in temperature.
10:10 Lighting of heaters begun, alternate heaters.
10:25 Second lighting, balance of heaters.
10:35 Lighting of heaters completed.
11:00 Decided westerly drift of about 4 miles per hour.
11:30 Dew point, 20° F. Relative humidity, 70 per cent.
11:55 Refueling of heaters begun; continued the balance of the night.
Mdt.
12:00 Westerly drift still continues.
A. m.
12:27 Ground showing crust outside heated area.
1:16 Draft opened to two holes.
1:42 Draft opened to three holes.
2:00 Ground crusting in irrigation furrows. Light wind from southwest blowing the smoke along the ground.
2:06 Wind shifting to west and northwest (4–6 miles per hour). Frost showing on alfalfa in field adjoining patch.
2:15 Wind shifting to east; no decrease in velocity.
3:57 Ground crusted hard outside heated area; heavy frost on shelter in check station; ice in irrigation ditches about 6 feet from heaters.
5:00 Frost showing about 7½ feet from heaters; ground hard about shelter but soft within 7½ feet of heaters.
5:16 Sunrise.
5:40 Some heaters beginning to burn out of oil.
6:42 Extinguishing of heaters begun.
6:52 Extinguishing of heaters completed.

Patch about 20 per cent in full bloom. Most conservative estimate placed damage at 20 per cent of bloom with bud injury negligible.

Lowest temperatures reached after sunrise when heaters were burning out of oil. Damaged buds no doubt frozen at that time.

A temperature station was located in the exact center of the plot, and another 300 feet due south of this and outside the heated area, for the purpose of furnishing a check on the outside temperature. Each station was equipped with a minimum thermometer and a 29-hour thermograph in a fruit-region instrument shelter. The shelter was set directly upon the surface of the plants and the thermometer bulb was 10 inches above the ground. A horizontal, registering, minimum thermometer with

clear liquid was placed upon the surface of the plants with its bulb exposed to the sky and used to measure the effect of the radiant heat upon the plants. The distance from the thermometer bulbs to the nearest heater was 13 feet 8 inches, the greatest possible distance. The instrumental equipment at the check station was an exact duplicate of that used in the heated area.

The stations were so located as to give the temperature in the heated area, and, as determined from that at the check station, the temperature which would have occurred had there been no lighting of heaters. This made possible the measurement of the increase in temperature brought about by the firing of the heaters by comparing the temperature in the heated area with that recorded simultaneously at the check station.

The experiment was carried on under natural frost conditions, and the heaters were lighted only when it was necessary to protect the buds from injury, namely, on the nights of April 12–13, 19–20, and 20–21.

Temperature data are shown graphically in Figures 1, 2, and 3 on nights when firing was done.

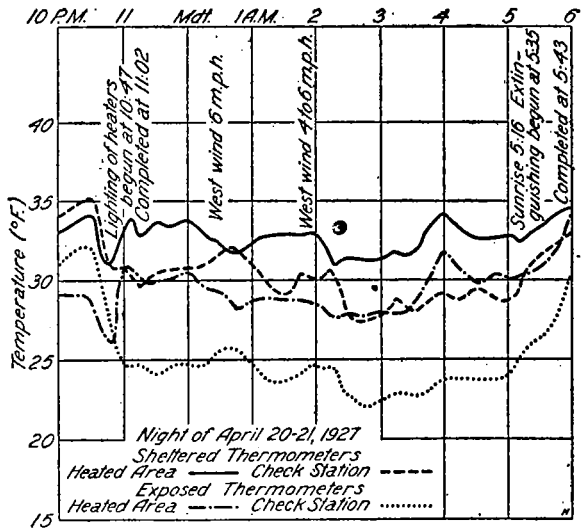
The lowest temperature ever recorded during the strawberry season occurred this year.

About 10 per cent of the buds were in full bloom on the night of April 12-13, and at the time of the severe freeze, April 19–20, about 20 per cent of the buds were in full bloom.

On the night of April 12–13 the heaters were placed directly upon the plants, with the top of the stack about 22 inches above the surface of the plants. The draft was opened to one hole, except for the last hour in the morning, when it was opened to two holes. Examination of the chart for this night, Figure 1, shows the maximum rise in temperature occurred between 5:45 and 6 a. m., when the increase in temperature was 6.1° F. inside the instrument shelter and 7.7° F. on the surface of the plants, as shown by direct comparison of the readings after allowing for the average differences before firing of the heaters was begun.

Computations involving all of the readings taken while the heaters were burning (first reading after lighting of heaters to the last one before extinguishing was completed) show the average rise in temperature inside the instrument shelter to be 3.5° F. and on the surface of the plants 4.7° F. The influence of the direct radiation from the heaters on the temperature at the surface of the plants is shown by comparing the exposed thermometer readings. This can also be shown by comparing the difference between the sheltered and exposed thermometers in the heated area before the heaters were lighted with the difference while the heaters were burning. The average difference between the readings of the sheltered and the exposed thermometers, as indicated by a set of comparative readings taken on the night of April 13–14, when no heaters were lighted, and before lighting on the night of April 12–13, was 4.1° F. The average difference after the lighting of the heaters, night of April 12–13, was 3.9° F., making a rise of 0.2° F., due to the heating. Adding this to the rise of 3.5° F. shown by the sheltered thermometer indicates an average effective increase in temperature at the surface of the plants of 3.7° F. The maximum effective rise in temperature was 8.3° F. at the surface of the plants.

On the night of April 19–20 the heaters were mounted upon metal tripods, so that the top of the stack was 30 inches above the surface of the plants. It was found necessary to burn the heaters with two to three draft holes open the last half of the night to secure adequate protection. From 1:42 a. m. until morning the heaters were operated at maximum capacity. The maximum increase in temperature inside the shelter was 9.0° F. at 4:58 a. m., shortly before sunrise. The average increase in temperature inside the shelter was 5.1° F. The maximum effective rise in temperature on the surface of the plants, including the rise due to direct radiation from the heaters, was 12.1° F., and the average effective increase in temperature was 8.4° F. by direct comparison of the readings from the exposed thermometers in the heated area and at the check station. The effective rise in temperature at the surface of the plants, as shown by comparing the difference between the exposed and sheltered thermometer readings before and after lighting of the heaters, was 11.7° F., and the average effective rise in temperature by this method was 7.2° F.



NOTES TO ACCOMPANY FIG. 3—NIGHT OF APRIL 20–21, 1927

P. m.
5:00 Dew point, 12° F. Relative humidity, 15 per cent. Temperature, 56.4° F. Northeast—4 miles per hour. Sky clear.
9:00 Very light wind shifting to west.
10:47 Lighting of heaters begun.
11:02 Lighting of heaters completd. Draft regulated to one hole.
11:03 Decided west wind—4 to 6 m. p. h.
A. m.
12:30 West wind still continues, but stronger than before.
1:00 West wind decreasing a little.
2:00 Haze in south causing lunar corona. West wind freshening to about 6 miles per hour.
2:10 Refilling of heaters begun and continued the balance of the night. Some heaters being filled all of the time.
3:00 West wind decreasing.
4:02 Few cirrus clouds on horizon to south and northeast. Still more of a decrease in the wind.
5:16 Sunrise.
5:30 Sky cloudy with cirrus.
5:35 Extinguishing of heaters begun.
5:43 Extinguishing of heaters completed.

Patch in about the same condition as on previous night as to bloom, etc. No injury noted upon inspection later in the day.

The heaters remained upon the tripods on the night of April 20–21. It was not found necessary to open the drafts more than one hole at any time during the night. A maximum increase of 5.1° F. in the shelter and 8.1° F. on the surface of the plants was secured. The average increase in temperature was 3.0° F. in the shelter and 5.2° F. on the surface of the plants as shown by direct comparison. The maximum effective rise in temperature on the surface of the plants by comparsion of the exposed and sheltered thermometers in the heated area before and after lighting of the heaters was 6.8° F., and the average effective rise was 3.9° F. by this method.

The apparent discrepancy in the values of the effective increase of temperature at the surface of the plants when computed by the two methods is, in all probability, due

to the incorrect assumption that the average differences between the readings of the several thermometers when no heaters were burning were the same at all times. On the night of April 13–14, when the set of comparative readings used as the basis for the differences was taken, there was no appreciable air movement; while on the nights of April 19–20 and 20–21 there was considerable wind, at times reaching a velocity of 4 to 6 miles per hour. This air movement would surely make some difference in the readings of the thermometers. Because of a moderate to fresh wind which blew during the early part of the evening on the last two nights, comparative readings could not be taken before it was necessary to light the heaters. The temperature dropped rapidly following a cessation of the wind. It is not unlikely that the range of differences on the nights of April 19–20 and 20–21 was large, due to intermittent breezes. This, presumably, would have been shown had it been possible to secure a set of comparative readings.

A detailed account of labor, fuel, and operating expenses was kept throughout the test.

The charges carried in the account for operating are based on the scale of wages actually in effect when the labor was performed. All of the labor of lighting the heaters and supervising was taken care of by one man, since the tract was so small that no more than one man was needed at any time during the firing. The labor of two men was required for the filling during the day.

The items listed under "equipment" are the articles which are necessary if heating is to be put on a practical working basis. The prices quoted for them were furnished by local dealers.

The tripods employed were made several years ago for use with an obsolete type of coal-burning orchard heater. The charges stated in the expense account were based on the original cost, approximately 15 years ago. Tripods purchased now would cost somewhat more.

The operating costs are divided into two parts. The first includes the costs involving interest on investment, depreciation on equipment, and the cost of placing the heaters in and taking them from the patch whether it is necessary to use them or not. These are termed "fixed expenses" because there is little change from year to year. The second part consists of the costs incident to the actual firing of the heaters, such as labor and fuel costs. These are given for each night when firing was necessary and are carried to considerable detail.

The equipment used was that required for 1 acre. Hence the expenses listed represent the cost of heating a tract 1 acre in extent. However, the test plot was slightly less than 1 acre in size.

VARIABLE OPERATING EXPENSES

[Night of April 12–13, 1927]

Fuel consumed, 173 gallons, at $0.075 per gallon	$12.98
Hauling fuel to the patch	.73
Refilling heaters after firing	1.60
Firing labor	5.00
Lighting mixture	.22
Total expenses for the night	20.53

Burning time: One draft hole open 2 hours 38 minutes; two draft holes open 1 hour; total burning time, 3 hours 38 minutes.

[Night of April 19–20, 1927]

Fuel consumed, 590 gallons, at $0.075 per gallon	$44.25
Hauling fuel to patch	2.48
Refilling after firing	1.60
Firing labor	5.00
Labor for refilling during the night [1]	4.00
Lighting mixture	.22
Total expenses for the night	57.55

Burning time: One draft hole open 3 hours 6 minutes; two draft holes open 0 hour 26 minutes; three draft holes open 5 hours 10 minutes; total burning time, 8 hours 42 minutes.

[Night of April 20–21, 1927]

Fuel consumed, 300 gallons, at $0.075 per gallon	$22.50
Hauling fuel to patch	1.26
Refilling after firing	1.60
Firing labor	5.00
Labor for refilling during the night [1]	3.00
Lighting mixture	.22
Total expenses for the night	33.58

Burning time: One draft hole open 7 hours.

Total variable operating expenses for the season for 1 acre	$111.66

EQUIPMENT INVESTMENT

1 500-gallon tank at $45.50	$45.50
1 wagon at $65	65.00
2 buckets at $1.35	2.70
96 heaters at $1.38	132.48
96 tripods at $0.05	4.80
1 lighting torch at $3.75	3.75
2 thermometers at $3.75	7.50
Total investment	261.73
288 gallons of oil at $0.075 per gallon carried over	21.60
Hauling fuel to ranch	1.21
Total	22.81

FIXED OPERATING EXPENSES

Interest:	
6 per cent on $22.81 for 10 months	$1.14
6 per cent on $261.73, original investment	15.70
	16.84
Depreciation on equipment:	
Storage tank, 5 per cent on $45.50	2.28
Wagon, 10 per cent on $65	6.50
Torch, 20 per cent on $3.75	.75
Buckets, 20 per cent on $2.70	.54
Heaters, 10 per cent on $132.48	13.25
Thermometers, 5 per cent on $7.50	.38
	23.70
Seasonal operation:	
Setting heaters in patch and filling	2.60
Emptying and taking in heaters	3.40
	6.00
Total fixed operating expenses	46.54
Total variable operating expenses	111.66
Total expenses for the season for one acre	158.20

The Kennewick-Richland section of the Yakima Valley is the earliest fruit-growing district of the Pacific North-

[1] The labor charge for refueling the heaters during the burning period could have been materially reduced, or even avoided entirely, if larger capacity heaters had been used. In effect, the use of larger heaters would have reduced the operating expense on the test plot by about 6 per cent.

(To face p. 356)

FIG. 4.—Type of orchard heater used in strawberry protection experiment in place on tripod

FIG. 5.—Instrument shelter in protected area

Fig. 6.—General view of protected strawberry acreage, with heaters in position ready for firing

west. The strawberry crop is harvested early and commands a high price, as is evidenced by the following table of returns to the growers for the 1927 season, taken from a published statement by the Kennewick branch of the Yakima Fruit Growers Association:

	Per crate
May 19 to 21	$6.20 to $5.80
May 22 to 25	4.80 to 4.40
May 26 to 28	4.53 to 4.13
May 29 to June 1	4.23 to 3.83
June 2 to 4	4.30 to 3.90
June 5 to 8	4.15 to 3.75

The prices quoted in the above table are representative of the returns to the growers for early strawberries during the past few years. These prices will undoubtedly be paid in the future, as long as the strawberries can be placed upon the market in advance of those from competing sections as has been done in the past when no injury resulted from frost.

In the event of a serious frost, enough late bloom may be uninjured to mature a fair crop (from 20 to 50 per cent of a normal yield). However, the berries are usually small and of poor quality and are placed upon a declining market in direct competition with strawberries from other districts more favorably located with respect to the markets. With the prices which have prevailed for the early berries for the past few years and a strawberry bed producing 200 crates or more per acre, it is readily seen that considerable expense would be justified in saving the early bloom.

Although berries have been grown on the test plot or adjoining ground for four years, the first crate to be shipped from the Kennewick-Richland district was never picked from this tract until this year. This would seem to bear out the contention that the early bloom was killed in the unprotected patches this year.

The following table gives the dates on which the first crate of berries was picked in the Kennewick-Richland district, and the date on which the first berries were picked on the patch used for the test:

	Test plot	Kennewick-Richland		Test plot	Kennewick-Richland
1924	May 10	May 6	1926	Apr. 30	Apr. 24
1925	May 5	May 2	1927	May 14	May 19

The length of time during which firing of the heaters was necessary on the nights of April 19–20 and 20–21 was somewhat longer than that usually experienced in the Yakima Valley, and the temperatures were the lowest ever recorded during the stawberry blossom period. If a grower intends to insure a crop every year, it is essential that he be prepared to meet the worst conditions possible, both as to temperature and length of firing period.

The results of this experiment prove conclusively that strawberries and other low-lying ground crops can be protected from frost injury by methods of artificial heating. The chief consideration is the cost of the heating operation in comparison with the net returns from the crop.

In order to render heating a paying proposition, it is necessary to have a well-kept, full-producing bed. The test plot was not such a patch. A large number of the plants were winterkilled in December, 1924, and new runners set out by the remaining plants in following years were sufficient to cover only about 60 per cent of the available ground. This fact should be borne in mind when one is considering the yield from the heated area. One hundred and forty-two standard 24-pint crates were harvested from the test plot. Assuming that only 60 per cent of the available ground produced berries, the yield per acre was 237 crates. The annual yield when no injury results from frost varies from 200 to 350 crates per acre.

It was not possible to secure comparative records of yields between the heated area and an unheated area, because all of the bed was equipped with heating apparatus. However, yield records from the patch of Mr. G. W. Krohling, of Richland, are available. Mr. Krohling used the same type of heater as that used on the test plot on one half of his bed, leaving the other half with no protection against frost. At each picking the yield per row in the heated part was 24 to 30 hallocks (one pint containers), and in the unheated tract, from 4 to 7 hallocks per row.

The total harvest for the season showed the yield of the heated tract to be seven times as much as that of the unheated portion. The fruit loss was about 85 per cent of that harvested in the heated tract, or, in other words, a saving of 85 per cent of the crop was effected by the use of the heaters. Such a saving with the current prices would pay for all the expense of operating the heaters and in addition would yield the grower a substantial return. No temperature data or operating costs are available from this patch.

In studying the cost of heating, the unusual conditions which existed this year must be given due consideration. The unusual length of the firing periods and the record-breaking low temperatures during the 1927 season made the cost of heating somewhat greater than the average over a period of years. The real benefits derived from heating can be determined not from the records of one season only but rather by examining the data covering a period of several years with frosts of varying intensity.

It must be remembered that the cost of heating a larger tract would be somewhat less per acre than that of the test plot under discussion. The labor involved in lighting and regulating the heaters on a tract four or five times as large as the test plot would not be appreciably greater than for the test plot alone.

About one-half acre of Mr. C. A. Hoadley's strawberry bed, three-quarters of a mile south of Kennewick, was equipped with 66 Kennewick briquet heaters, with extensions on the legs so that the top of the heater was 36 inches above the plants. On the morning of April 20 the test was abandoned because of the failure of the heaters to raise the temperature sufficiently to prevent injury to the buds.

Two other growers experimenting with the same type of heater also failed because of the inefficiency of the heaters. These facts seem to show that this particular type of heater is not adapted to the successful heating of strawberries or other ground crops.